PROCEEDINGS OF SCIENCE

Recent results from BESIII

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Using about 226×10^6 J/ψ events and 106×10^6 ψ' events collected with the BESIII detector at the BEPCII e^+e^- collider, the Dalitz plot of $\eta'\to\eta\pi^+\pi^-$ decay is studied, the direct measurement of $a_0^0(980)-f_0(980)$ mixing is performed, $X(2120)$ and $X(2370)$ are observed in the $\pi^+\pi^-\eta'$ invariant mass spectrum, $\psi'\to\gamma\pi^0$ and $\psi'\to\gamma\eta$ are observed for the first time, and the decays $\chi_{cJ}\to\gamma V$ ($V=\phi$, ρ^0, ω) are studied.

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1. BESIII and BEPCII

BESIII/BEPCII [1] is a major upgrade of the BESII experiment at the BEPC accelerator [2] for studies of hadron spectroscopy and τ-charm physics. The analyses reported here use data samples of 226×10^6 J/ψ events and 106×10^6 ψ' events.

2. Measurement of the Matrix Element for the Decay $\eta'\to\eta\pi^+\pi^-$

Investigation of matrix elements for particle decays is of paramount importance for obtaining deeper insight into the dynamics of the processes and into the structure of particles. The hadronic decays of the η' meson have been extremely valuable in studies devoted to chiral theory [3], the effect of the gluon component [4], and the possible nonet of light scalars [5].

The branching fraction of $J/\psi\to\gamma\eta'$ is measured to be $(4.82\pm0.03\ (\text{stat})\pm0.25\ (\text{sys}))\times10^{-3}$ [6], which is consistent with the PDG value [7] within 1.5 σ. The Dalitz plot distribution for the decay $\eta'\to\eta\pi^+\pi^-$ is described by two variables: $X=\frac{\sqrt{3}}{Q}(T_{\pi^+}-T_{\pi^-})$, $Y=\frac{m_\eta+2m_\pi}{m_\pi}\frac{T_\eta}{Q}-1$, where $T_{\pi,\eta}$ denote the kinetic energies of mesons in the η' rest frame and $Q=T_\eta+T_{\pi^+}+T_{\pi^-}$. The squared absolute value of the decay amplitude is expanded around the center of the corresponding Dalitz plot: $M^2=A(1+aY+bY^2+cX+dX^2)$, where a,b,c and d are real parameters and A is a normalization factor. This parametrization is called the general decomposition. A second parametrization is the linear one: $M^2=A(|1+\alpha Y|^2+cX+dX^2)$, where α is a complex parameter.

Dalitz plot parameters are obtained by minimizing $\chi^2(N,a,b,c,d)=\sum_i^{n_{bin}}\frac{(D_i-NM_i)^2}{\sigma_i^2}$. Here the index i enumerates cells in Dalitz plot (empty cells outside the Dalitz plot boundaries are excluded), N is normalization factor, a,b,c and d are the Dalitz plot parameters. The M_i and D_i are the numbers of (weighted) entries in the i-th bin of the two-dimensional histograms in the Dalitz variables for MC and for the background-subtracted data, respectively. The statistical error σ includes background subtraction and MC statistical errors. The MC histogram is obtained as follows: $M_i=\sum_{j=1}^{N_{ev}}(1+aY_j+bY_j^2+cX_j+dX_j^2)$, for the general decomposition parametrization, where the index j is over the generated events and X_j and Y_j are the generated true values of Dalitz variables. Similarly for the linear parametrization, $M_i=\sum_{j=1}^{N_{ev}}(|1+\alpha Y_j|^2+cX_j+dX_j^2)$.

The fitted values of the parameters of the matrix element for the generalized and linear representations are: $a=-0.047\pm0.011\pm0.003, b=-0.069\pm0.019\pm0.009, c=+0.019\pm0.011\pm0.003, d=-0.073\pm0.012\pm0.003$, and $\text{Re}(\alpha)=-0.033\pm0.005\pm0.003, \text{Im}(\alpha)=0.000\pm0.049\pm0.001, c=+0.018\pm0.009\pm0.003, d=-0.059\pm0.012\pm0.004$, respectively. Here the first errors are statistical, the second systematic. The fitted results are shown in Fig. 1.

3. Study of a_0^0(980)–f_0(980) mixing

The study of $a_0^0(980)$ and $f_0(980)$ nature is one of the central topics in light hadron spectroscopy. The mixing between $a_0^0(980)$ and $f_0(980)$ is expected to shed light on the nature of these two resonances. Two kinds of mixing intensities ξ_{af} and ξ_{fa} for the $a_0^0(980)\to f_0(980)$ and $f_0(980)\to a_0^0(980)$ transitions are expressed as [8]: $\xi_{fa}=\frac{Br(J/\psi\to\phi f_0(980)\to\phi a_0^0(980)\to\phi\eta\pi^0)}{Br(J/\psi\to\phi f_0\to\phi\pi\pi)}$, $\xi_{af}=\frac{Br(\psi'\to\gamma\chi_{c1}\to\gamma\pi^0a_0^0(980)\to\gamma\pi^0f_0(980)\to\gamma\pi^0\pi^+\pi^-)}{Br(\psi'\to\gamma\chi_{c1}\to\gamma\pi^0a_0^0\to\gamma\pi^0\pi^0\eta)}$.

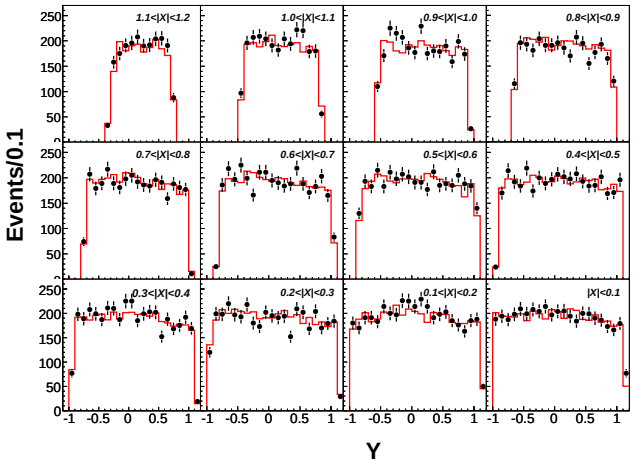

Figure 1: Experimental distributions of the variable Y in various intervals of X with the fitting function (histogram) for the general decomposition parametrization.

For the decay $J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0$, a simultaneous unbinned maximum likelihood fit to the $\eta\pi^0$ mass spectra recoiling against the ϕ signal and the ϕ mass sideband is performed. The fit yields $N(f_0 \to a_0^0) = 25.8 \pm 8.6$ (stat) events for the mixing signal with a statistical significance of 3.4σ. The $\mathcal{B}(J/\psi \to \phi f_0(980) \to \phi a_0^0(980) \to \phi\eta\pi^0)$ is measured to be $(3.2 \pm 1.1\ (\text{stat}) \pm 0.8\ (\text{sys})) \times 10^{-6}$ ($< 5.1 \times 10^{-6}$ at 90% C.L.).

For the decay $\psi' \to \gamma\chi_{c1} \to \gamma\pi^0 a_0^0(980) \to \gamma\pi^0 f_0(980) \to \gamma\pi^0\pi^+\pi^-$, a simultaneous fit is performed to the $\pi^+\pi^-$ invariant mass spectra in the χ_{c1} mass window and the χ_{c1} mass sideband. The fit yields $N(a_0^0 \to f_0) = 6.4 \pm 3.2$ (stat) events for the mixing signal with a statistical significance of 1.9σ. The $\mathcal{B}(\psi' \to \gamma\chi_{c1} \to \gamma\pi^0 a_0^0(980) \to \gamma\pi^0 f_0(980) \to \gamma\pi^0\pi^+\pi^-)$ is measured to be $(2.7 \pm 1.4(\text{stat}) \pm 0.7(\text{sys})) \times 10^{-7}$ ($< 5.9 \times 10^{-7}$ at 90% C.L.).

The mixing intensity ξ_{fa} for the $f_0(980) \to a_0^0(980)$ transition is calculated to be $\xi_{fa} = 0.6 \pm 0.2\ (\text{stat}) \pm 0.2\ (\text{sys})\%$. The mixing intensity ξ_{af} for the $a_0^0(980) \to f_0(980)$ transition is calculated to be $\xi_{af} = 0.3 \pm 0.2\ (\text{stat}) \pm 0.1\ (\text{sys})\%$.

4. Observation of three resonances in $J/\psi \to \gamma\eta'\pi^+\pi^-$

The X(1835) is observed in the $J/\psi \to \gamma\eta'\pi^+\pi^-$ with a statistical significance of 7.7 σ by the BESII experiment. The possible interpretations of the X(1835) include a $p\bar{p}$ bound state, a glueball and a radial excitation of η' meson, etc. A high statistical data sample collected with the BESIII provides an opportunity to confirm the existence of the X(1835) and look for possible related states that decay to $\pi^+\pi^-\eta'$.

The $\eta'\pi^+\pi^-$ invariant mass spectrum for the combined two η' decay, $\eta' \to \eta\pi^+\pi^-$ and $\eta' \to \gamma\rho$, is presented in Fig. 2. Two new resonances, the X(2120) and the X(2370), are observed with statistical significances larger than 7.2σ and 6.4σ, respectively. The masses and widths are measured to be $M = 1836.5 \pm 3.0^{+5.6}_{-2.1}$ MeV/c^2 and $\Gamma = 190 \pm 9^{+38}_{-36}$ MeV/c^2 for the X(1835), $M = 2122.4 \pm 6.7^{+4.7}_{2.7}$ MeV/c^2 and $\Gamma = 83 \pm 16^{+31}_{-11}$ MeV/c^2 for the X(2120), $M = 2376.3 \pm 8.7^{+3.2}_{-4.3}$ MeV/c^2 and $\Gamma = 83 \pm 17^{+44}_{-6}$ MeV/c^2 for the X(2370), respectively. The product branching fraction is $\mathcal{B}(J/\psi \to \gamma X(1835))\mathcal{B}(X(1835) \to \pi^+\pi^-\eta') = (2.71 \pm 0.09\ (\text{stat})^{+0.49}_{-0.35}\ (\text{syst})) \times 10^{-4}$,

and the corresponding angular distribution of the radiative photon is consistent with a pseudoscalar assignment for the X(1835). The mass of the X(1835) is consistent with the BESII result, but the width is significantly larger.

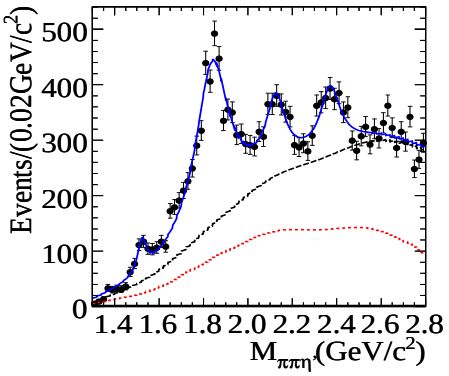

Figure 2: The $\eta'\pi^+\pi^-$ invariant mass distribution for the selected events from the two η' decay modes. The dash-dot line is contributions of non-η' events and the $\eta'\pi^+\pi^-\pi^0$ background and the dash line is the total background contribution.

5. Evidence for ψ' decays into $\gamma\pi^0$ and $\gamma\eta$

The study of vector charmonium radiative decay to a pseudoscalar meson $P = (\pi^0, \eta, \eta')$ provides important tests for various phenomenological mechanisms, such as vector meson dominance model (VDM) [9, 10], two-gluon couplings to $q\bar{q}$ states [10], mixing of $\eta_c - \eta^{(\prime)}$ [11], and final-state radiation by light quarks [9].

For $P = \eta$ or η', the ratio of $R_{J/\psi} \equiv \mathscr{B}(J/\psi \to \gamma\eta)/\mathscr{B}(J/\psi \to \gamma\eta')$ can be predicted by first order of perturbation theory [9], and comparing to η and η' production in ψ' radiative decays, the same ratio $R_{\psi'}$ can be defined and $R_{\psi'} \approx R_{J/\psi}$ is expected [12]. The decay $\psi' \to \gamma\pi^0$ is suppressed because the photon can only be from final state radiation off one of the quarks. In Ref. [13], the contribution from $\psi' \to \gamma^* \to \gamma\pi^0$ is calculated and $\mathscr{B}(\psi' \to \gamma\pi^0) = 2.19 \times 10^{-7}$ is obtained, which is compatible to the VDM contribution and does not contradict the upper limit 5.0×10^{-6} (at 90% C.L.) reported by the CLEO Collaboration [12].

The branching fractions are listed in Table 5 [14]. We obtain $R_{\psi'} = (1.10 \pm 0.38 \pm 0.07)\%$, which is the first measurement and is below the 90% C.L. upper bound determined by the CLEO Collaboration [12]. The corresponding $\eta : \eta'$ production ratio at J/ψ resonance was measured to be $R_{J/\psi} = (21.1 \pm 0.9)\%$ [12]. $R_{\psi'}$ is unexpectedly smaller than that at the J/ψ resonance by an order of magnitude. Such a small value of $R_{\psi'}$ poses a great challenge to our understanding of the decay properties of the charmonium states.

6. Study of χ_{cJ} radiative decays into a vector meson

J/ψ and ψ' double radiative decays $\psi \to \gamma X \to \gamma\gamma V$ (ρ^0, ω, ϕ) provide a favorable place to extract information on the flavor content of the C-even resonance X and to study gluon hadronization dynamics. The recent CLEO experimental results [15] for $\mathscr{B}(\chi_{c1} \to \gamma\rho^0$, $\gamma\omega$, and $\gamma\phi)$ are

Mode	BESIII	Combined BESIII	PDG
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^-\pi^0)$	$1.78 \pm 0.72 \pm 0.17$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$		
$\psi' \to \gamma\eta'(\pi^+\pi^-\eta)$	$120 \pm 5 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8
$\to \gamma\eta'(\pi^+\pi^-\gamma)$	$129 \pm 3 \pm 8$		

Table 1: Branching fractions (10^{-6}). The first errors are statistical and the second systematic.

Mode	$\mathscr{B}$ ($\times 10^{-6}$)	Channel	$\mathscr{B}$ ($\times 10^{-6}$)	Channel	$\mathscr{B}$ ($\times 10^{-6}$)
$\chi_{c0} \to \gamma\phi$	$9.5 \pm 4.2 \pm 0.8$	$\chi_{c0} \to \gamma\rho^0$	<10.2	$\chi_{c0} \to \gamma\omega$	<12.7
$\chi_{c1} \to \gamma\phi$	$25.8 \pm 5.2 \pm 2.0$	$\chi_{c1} \to \gamma\rho^0$	$228 \pm 13 \pm 16$	$\chi_{c1} \to \gamma\omega$	$69.7 \pm 7.2 \pm 5.6$
$\chi_{c2} \to \gamma\phi$	<8.0	$\chi_{c2} \to \gamma\rho^0$	<20.4	$\chi_{c2} \to \gamma\omega$	<6.0

Table 2: Results of $\chi_{cJ} \to \gamma V$. The upper limits are at the 90% C.L.

an order of magnitude higher than the corresponding theoretical predictions [16]. By including hadronic loop contributions, a recent perturbative Quantum ChromoDynamics (pQCD) calculation [17] obtains results in agreement with the experimental measurements of $\mathscr{B}(\chi_{c1} \to \gamma V)$.

After the event selection criteria, we can see clear χ_{c1} signals in all decay modes, while χ_{c0} and χ_{c2} signals are insignificant. Each of the distributions is fitted with vector meson mass sideband background plus a 2nd order polynomial background and three χ_{cJ} resonances as the signal shapes. The measured branching fractions are summarized in Table 2.

The longitudinal (transverse) polarization exhibits a $\cos^2\Theta$ ($\sin^2\Theta$) dependence [18], and the angular distribution is expressed as: $\frac{dN}{d\cos\theta} \propto |A_L|^2\cos^2\Theta + \frac{1}{2}|A_T|^2\sin^2\Theta$, where A_L and A_T are the longitudinal and transverse polarization amplitudes, respectively, and Θ is defined as the angle between the vector meson flight direction in the χ_{cJ} rest frame and either the π^+/K^+ direction in the ρ^0/ϕ rest frame or the normal to the ω decay plane in the ω rest frame.

By fitting the angular distributions, the values of the fraction of the transverse component are determined to be $0.29^{+0.13+0.10}_{-0.12-0.09}$, $0.158 \pm 0.034^{+0.015}_{-0.014}$, and $0.247^{+0.090+0.044}_{-0.087-0.026}$ for $\chi_{c1} \to \gamma\phi$, $\chi_{c1} \to \gamma\rho^0$, and $\chi_{c1} \to \gamma\omega$, respectively. Our measurement of the polarization of the vector mesons indicates that the longitudinal component is dominant in $\chi_{c1} \to \gamma V$ decays, as expected for an axial-vector particle decaying into a vector (ϕ, ρ^0, and ω) and a γ in the framework of the vector dominance model.

7. Summary

Using about 226×10^6 J/ψ events and 106×10^6 ψ' events, some recent preliminary results are shown here. They include the analysis of Dalitz plot of $\eta' \to \eta\pi^+\pi^-$ decay, the direct measurement of $a_0^0(980) - f_0(980)$ mixing, the observations of two new resonances, $X(2120)$ and $X(2370)$, in the $\pi^+\pi^-\eta'$ invariant mass spectrum, the studies of $\psi' \to \gamma\pi^0$, $\psi' \to \gamma\eta$, and $\chi_{cJ} \to \gamma V$ ($V = \phi$, ρ^0, ω).

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